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# Standard Test Method for Impedance and Absorption of Acoustical Materials Using a Tube, Two Microphones, and a Digital Frequency Analysis System[1]

This standard is issued under the fixed designation E 1050; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

## 1. Scope

1.1 This test method covers the use of an impedance tube and the use of a two-microphone method and a digital frequency analysis system for the measurement of normal incidence sound absorption coefficients and normal specific acoustic impedance ratios of materials.

1.2 *This standard does not purport to address the safety problems associated with its use. It is the responsibility of the user of this standard to consult and establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

## 2. Referenced Documents

2.1 *ASTM Standards:*

C 634 Terminology Relating to Environmental Acoustics[2]
C 384 Test Method for Impedance and Absorption of Acoustical Materials by the Impedance Tube Method[2]
E 548 Practice for Generic Criteria for Use in the Evaluation of Testing and Inspection Agencies[3]

## 3. Terminology

3.1 *Definitions*—For definitions of terms used in this test method, see Terminology C 634.[4]

3.2 *Symbols*—The following symbols are used in Section 8 (Procedure):

3.2.1 $b\rho c$—normal specific acoustic susceptance ratio.

3.2.2 $c$—speed of sound in air within the tube at the test temperature, m/s.

3.2.3 $d$—inside diameter of tube, m.

3.2.4 $f$—frequency, Hz.

3.2.5 $f_u$—highest frequency of interest, Hz.

3.2.6 $g\rho c$—normal specific acoustic conductance ratio.

3.2.7 $G_{11}$, $G_{22}$—autospectra of the acoustic pressure signal at microphone locations 1 and 2, respectively.

3.2.8 $G_{12}$—cross spectrum of the acoustic pressure signals at microphone locations 1 and 2.

3.2.9 $H$—transfer function of the two microphone signals corrected for microphone response mismatch, $G_{12}/G_{11}$.

3.2.10 $\hat{H}$—measured transfer function of the two microphone signals.

3.2.11 $\hat{H}^I$, $\hat{H}^{II}$—calibration transfer functions for the microphones in the standard and interchanged locations, respectively.

3.2.12 $\hat{H}_c$—complex microphone calibration factor.

3.2.13 $j$—equals $\sqrt{-1}$.

3.2.14 $k$—equals $2\pi f/c$; wavenumber, $m^{-1}$.

3.2.15 $l$—distance from the test sample to the center of the nearest microphone, m.

3.2.16 $l_1$—distance from the test sample to the center of microphone number 1, m.

3.2.17 $r/\rho c$—normal specific acoustic resistance ratio.

3.2.18 $R$—complex acoustic reflection coefficient.

3.2.19 $s$—center-to-center spacing between microphones, m.

3.2.20 $T$—sampling record length, s.

3.2.21 $x/\rho c$—normal specific acoustic reactance ratio.

3.2.22 $y\rho c$—normal specific acoustic admittance ratio.

3.2.23 $z/\rho c$—normal specific acoustic impedance ratio.

3.2.24 $\alpha$—normal incidence sound absorption coefficient.

3.2.25 $\phi$—phase of the complex transfer function, rad.

3.2.26 $\phi_R$—phase of the complex acoustic reflection coefficient, rad.

3.2.27 $\rho$—density of air, kg/m³.

3.3 *Subscripts, Superscripts, and Other Notation*—The following symbols are used in Section 8 (Procedure):

3.3.1 $c$—calibration.

3.3.2 $i$—imaginary part.

3.3.3 $r$—real part.

3.3.4 $R$—reflection coefficient.

3.3.5 $^{I}$, $^{II}$—calibration quantities measured with microphones placed in the standard and interchanged locations, respectively.

3.3.6 $^{*}$—complex conjugate.

3.3.7 $\hat{}$—measured quantity prior to correction for amplitude and phase mismatch.

3.3.8 $| \, |$—magnitude of a complex quantity.

## 4. Summary of Test Method

4.1 This test method is similar to Test Method C 384[5] in that it uses an impedance tube with a sound source connected to one end and the test sample mounted within the tube at the other end. However in this test method, plane waves are generated in a tube by a random noise source, and

[1] This test method is under the jurisdiction of ASTM Committee E-33 on Environmental Acoustics and is the direct responsibility of Subcommittee E33.01 on Sound Absorption.

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[2] *Annual Book of ASTM Standards*, Vol 04.06.

[3] *Annual Book of ASTM Standards*, Vol 14.02.

[4] Definitions C 634 – 81a was the edition used for this test method.

[5] Test Method C 384 – 77 was the edition used for this test method.

the decomposition of the standing wave is achieved with the measurement of acoustic pressures at two fixed locations close to the sample using wall-mounted microphones. Using a digital frequency analysis system, the complex acoustic transfer function of the two microphone signals is determined and used to compute the normal incidence absorption and impedance ratios of the acoustic material.

4.2 This test method is intended to provide an alternative measurement technique to Test Method C 384.

## 5. Significance and Use

5.1 Since the impedance ratios of a sound absorptive material are related to its physical properties, such as airflow resistance, porosity, elasticity, or density, measurements described in this test method are useful in basic research and product development of sound absorptive materials.

5.2 Normal sound absorption coefficients are more useful than random incidence absorption coefficients in certain situations. They are used, for example, to predict the effect of placing material in a small acoustical space, such as inside a machine enclosure.

5.3 For materials that are locally reacting, random incidence absorption coefficients can be calculated or estimated from measurements conducted on a small test specimen when it is impossible or impractical to procure a larger specimen for a reverberation room measurement.

## 6. Apparatus

6.1 The apparatus is essentially a tube with a test specimen at one end and a loudspeaker at the other. Microphones are mounted at two locations along the wall of the tube. A digital frequency analysis system is used for data acquisition and processing.

6.2 *Tube:*

6.2.1 *Construction*—The interior cross section of the tube shall be circular or rectangular and shall be uniform from a position one diameter (or largest dimension if rectangular) upstream of the microphones to the end where the test specimen is mounted. The tube shall be straight and its inside surface shall be both smooth and free of dust to maintain low attenuation. The tube walls shall be massive and sufficiently rigid so that sound energy transmission through them is negligible. The tube may be made of almost any material (that is, metal, wood, or plastic).

6.2.2 *Diameter*—The upper limits[6] of frequency or tube diameter for circular tubes are:

$$f < 0.586\, c/d \text{ or } d < 0.586\, c/f \tag{1}$$

where:

$f$ = frequency, Hz,
$c$ = speed of sound in the tube, m/s, and
$d$ = diameter of the tube, m.

6.2.2.1 For rectangular tubes, with $d$ defined as the larger cross section dimension, the upper limits are:

$$f < 0.500\, c/d \text{ or } d < 0.500\, c/f \tag{2}$$

6.2.2.2 It is best to work well below these limits whether the tube is circular or rectangular. At frequencies above these limits, cross modes may develop and the incident and reflected waves in the tube are not likely to be plane waves. If sound with a frequency below this limit enters the tube as a non-plane wave, it will become a plane wave after traveling a short distance. For this reason, no measurement should be made closer than one tube diameter to the sound source.

6.2.3 *Length*—The length of the tube should be kept as short as possible to help maintain the required signal-to-noise ratio and to reduce added absorption due to the tube. However, the required distances between source, microphones, and test specimen must always be maintained. (See 6.5.2 and 6.5.3.)

6.3 *Test Specimen Holder:*

6.3.1 *Size and Construction*—The specimen holder is a detachable extension of the tube and must make an airtight fit with the end of the tube opposite the sound source. Provision must be made for mounting the specimen with its face in a known position and backing the specimen with a massive sound-reflective septum. For some measurements, an airspace of known dimensions must be maintained between the specimen and the septum.

6.4 *Sound Source:*

6.4.1 *Kind and Placement*—The sound source should face directly into the tube and have a relatively flat frequency response (that is, ±10 dB) over the frequency range of interest. For example, a loudspeaker or horn-driver, coupled to a short exponential horn should be adequate. The sound-generating mechanism shall be isolated from the tube to minimize structure-borne vibration transmission.

6.4.2 *Signal-to-Noise Ratio*—The sound source shall generate a sound level at each microphone location that is at least 10 dB greater than ambient noise (source off) over the frequency range of interest. Test data for which this criteria is not met should be identified accordingly.

6.5 *Microphones:*

6.5.1 *Type*—Two identical microphones must be used and each must be mounted according to 6.5.4. The diameter of the microphones, although not critical, must be sufficiently small to physically provide the required spacing. Since even a small mismatch in amplitude or phase response between the microphones can cause errors in the measurement, a correction procedure is mandatory. It is recommended that the approach described in 8.3, or a comparable method, be used to correct for microphone mismatch.

6.5.2 *Spacing*—The microphone spacing is chosen in accordance with the highest frequency of interest, that is,

$$s \ll c/2f_m \tag{3}$$

where:

$s$ = the microphone spacing,
$c$ = the speed of sound, and
$f_m$ = the highest frequency of interest.

NOTE 1—$f_m$ must be less than the cutoff frequency as defined by Eq (1) or Eq (2).

6.5.3 *Location*—The distance from the source to the nearest microphone should be no less than one tube diameter. Spacing between the test specimen and the nearest microphone should be minimized to help maintain the required signal-to-noise ratio and to reduce added absorption due to the tube. If the test material is not homogeneous or its surface is not flat, higher order modes may be generated

[6] J. W. S. Rayleigh, *The Theory of Sound*, Dover Publications, Inc., New York, NY, Vol 2, 1896, p. 161, par. 301.

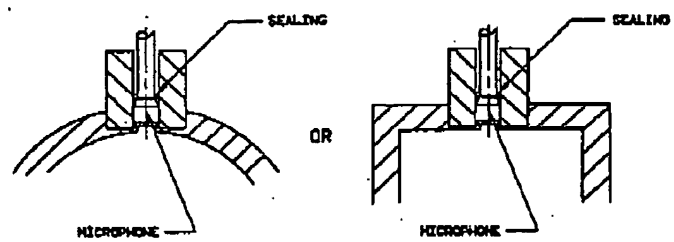


FIG. 1 Microphone Mounting (Typical)

which will decay exponentially as they propagate along the tube. To ensure that the plane wave amplitudes dominate those of local higher-order modes, the distance from the surface of the test specimen to the center of the nearest microphone should be at least one diameter in the case of a circular tube or the length of the larger cross-section dimension for a rectangular tube.

6.5.4 *Mounting*—It is desirable to mount both microphones flush with the interior surface of the tube. Care must be taken when microphones are removed from their mounting (that is, during switching) such that the original mounting geometry is maintained when they are replaced. A small recess is often necessary as shown in Fig. 1. This recess should be kept small and identical for both microphone mountings.

6.5.4.1 When utilizing side vented microphones, it is important that the pressure equalization vents not be blocked after the microphones are mounted. Blockage of the vents will alter the phase response of the microphones, resulting in large errors in the measurements.

6.6 *Test Signal:*

6.6.1 *Bandwidth*—It is recommended that the test-signal consist of broadband random noise; however, other test signals such as pseudo random noise or sine-sweep excitation could also be used.

6.7 *Output Measuring Equipment:*

6.7.1 *Digital Frequency Analysis System*—Each microphone output leads to a distinct input of a dual channel frequency analysis system. The analysis system must be capable of calculating the complex transfer function between its two input signals over the frequency range of interest.

6.7.2 *Computing Device*—A desktop calculator or a microcomputer, either separate from or part of the digital frequency analysis system may be necessary in order to determine the acoustic absorption coefficient and normal specific impedance ratio from the measured transfer function data. Although several methods of performing such calculations are available[7], one complete set of mathematical expressions is given in Section 8.

## 7. Test Specimens

7.1 *Shape and Size*—Each specimen must have the same shape and area as the tube cross section. It must fit snugly into the specimen holder, not so tightly that it bulges in the center, nor so loosely that there is space between its edge and the holder. The specimen should have a relatively flat surface, since the reflected wave from a very uneven surface may not have become a plane wave at the position of the first microphone. For example, if the specimen is a wedge of the kind used in anechoic rooms, the microphones must be placed far enough from the point of the wedge to measure the transfer function in the plane wave region (see 6.5.3).

7.2 *Alignment*—When the specimen has a very uneven back as, for example, a specimen cut from a hollow concrete block, a layer of putty-like material should be placed between it and the sound-reflective septum to seal the back of the specimen and to add enough thickness to make the front of the specimen parallel to the septum. (Both are perpendicular to the axis of the tube.) Otherwise, the unknown airspace may be the ruling factor in the result.

7.3 *Number*—A minimum of two specimens, more if the sample is not uniform, should be cut from the sample for the test. When the sample has a surface that is not uniform (for example, a fissured acoustical tile), specimens should be chosen to include the different kinds of surface in the proper proportion. If that is impossible, several specimens representative of the material should be cut. In any case, each specimen should be tested and the results should be averaged.

## 8. Procedure

8.1 *Apparatus and Instrumentation*—The apparatus and instrumentation are connected as shown in Fig. 2.

8.2 Measurement of the absorption coefficient, acoustic impedance ratio, reflection coefficient, etc., of a given material involves insertion of the sample into the end of the tube and measurement of the transfer function between the two microphone signals.[8] This transfer function data, along with the microphone spacing, the distance from the surface of the test specimen to the nearest microphone, and the air temperature are required for the evaluation of the normal incidence acoustical properties of the material over the frequency range of interest.

8.3 *Calibration:*

8.3.1 *Signal-to-Noise Ratio*—Measure the spectrum at each microphone with the sound source "on" and "off" to assure that conditions of 6.4.2 are met (that is, the sound source spectra at each microphone is at least 10 dB higher than ambient levels).

[7] R. Singh, "Acoustic Impedance Measurement Methods," *Shock and Vibration Digest*, Vol 14, No. 2, 1982, pp 3–9.

[8] Chung, J. Y., and Blaser, D. A., "Transfer Function Method of Measuring In-Duct Acoustic Properties I. Theory and II. Experiment," *Journal of the Acoustical Society of America*, 68 (3), 1980, pp. 907–921.

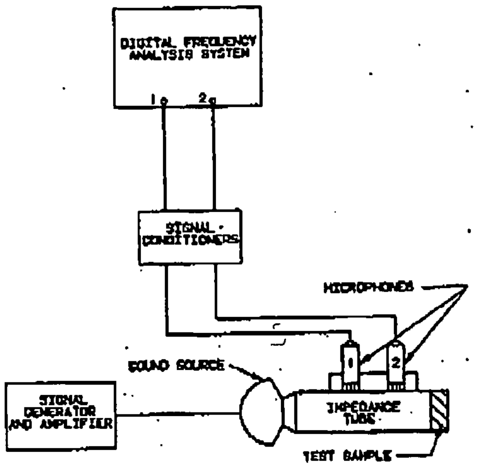


FIG. 2 Experimental Apparatus and Instrumentation

8.3.2 *Amplitude and Phase*—Since the transfer function is a complex ratio of the acoustic pressure responses, any mismatch in the amplitude or phase responses of the two microphone systems will affect the accuracy of the transfer function measurement.

8.3.3 The following sequence of measurements and computations provides a means of correcting the measured transfer function data for mismatch in both the amplitude and phase responses of the microphone systems.

8.3.4 *Step 1*—Place an absorptive specimen in the tube to prevent strong acoustic reflections and measure the following two transfer functions using the same mathematical expressions for both.

8.3.4.1 Place the microphones in the standard configuration of Fig. 2 (configuration I), and measure as follows:

$$\hat{H}^{I} = |\hat{H}^{I}| e^{j\hat{\phi}^{I}} = \hat{H}_r^{I} + j\,\hat{H}_i^{I}$$

8.3.4.2 Interchange the locations of the two microphones (configuration II) and measure as follows:

$$\hat{H}^{II} = |\hat{H}^{II}| e^{j\hat{\phi}^{II}} = \hat{H}_r^{II} + j\,\hat{H}_i^{II}$$

8.3.4.3 Care should be taken when interchanging the microphones to ensure that microphone 1 in configuration II occupies the precise location that microphone 2 occupied in configuration I, and vice versa.

8.3.5 *Step 2*—Compute the calibration factor $\hat{H}_c$ representing the amplitude and phase mismatches $|\hat{H}_c|$ and $\bar{\phi}_c$, using the following equation:

$$\hat{H}_c = (\hat{H}^{I} \cdot \hat{H}^{II})^{1/2} = |\hat{H}_c| e^{j\bar{\phi}_c}$$

where:

$$|\hat{H}_c| = (|\hat{H}^{I}| \cdot |\hat{H}^{II}|)^{1/2}$$
$$= \{[(\hat{H}_r^{I})^2 + (\hat{H}_i^{I})^2][(\hat{H}_r^{II})^2 + (\hat{H}_i^{II})^2]\}^{1/4}$$
$$\bar{\phi}_c = \tfrac{1}{2}(\bar{\phi}^{I} + \bar{\phi}^{II})$$
$$= \tfrac{1}{2}\,\mathrm{Tan}^{-1}\left[\frac{\hat{H}_i^{I}\hat{H}_r^{II} + \hat{H}_r^{I}\hat{H}_i^{II}}{\hat{H}_r^{I}\hat{H}_r^{II} - \hat{H}_i^{I}\hat{H}_i^{II}}\right]$$

where it is assumed that the phase mismatch is between $-\pi/2$ and $\pi/2$ radians.

8.3.6 *Step 3*—For subsequent tests, place the microphones in their standard locations (see Fig. 2). Insert the test specimen, and measure the transfer function as follows:

$$\hat{H} = |\hat{H}| e^{j\hat{\phi}} = \hat{H}_r + j\,\hat{H}_i$$

8.3.6.1 Correct for mismatch in the microphone responses using the following equation:

$$H = |H| e^{j\phi} = H_r + j\,H_i = \hat{H}/\hat{H}_c$$

where:

$$|H| = |\hat{H}|/|\hat{H}_c|,\ \phi = \bar{\phi} - \bar{\phi}_c$$
$$H_r = \frac{1}{|\hat{H}_c|}(\hat{H}_r\cos\bar{\phi}_c + \hat{H}_i\sin\bar{\phi}_c),$$

and

$$H_i = \frac{1}{|\hat{H}_c|}(\hat{H}_i\cos\bar{\phi}_c - \hat{H}_r\sin\bar{\phi}_c).$$

These values of $H$, $|H|$, $\phi$, $H_r$, and $H_i$ are then used in the expressions of 8.4.3 to determine the acoustic properties of the test specimen.

8.4 *Measurements:*

8.4.1 *Transfer Function*—Insert the test specimen and measure the complex acoustic transfer function as follows:

$$\hat{H} = \frac{G_{12}}{G_{11}} = |\hat{H}| e^{j\hat{\phi}} = \hat{H}_r + j\,\hat{H}_i \qquad (4)$$

NOTE —See 8.4.7 to minimize estimation errors.

8.4.1.1 Although not apparent from Eq (4), the transfer function physically represents the ratio of the Fourier transforms of the acoustic pressure at the two microphone locations (that is, microphone nearest test specimen/microphone nearest sound source). Since not all frequency analysis systems define the cross spectrum consistently, the adherence to this physical definition should be checked.

8.4.2 *Mismatch Correction*—Using the method described in 8.3, correct $\hat{H}$ for mismatch in the microphone amplitude and phase responses, and use the corrected transfer function, $H$, in the following computations.

8.4.3 *Complex Reflection Coefficient*—Calculate the complex reflection coefficient as follows:

$$R = |R| e^{j\phi_R} = R_r + jR_i$$
$$= \frac{H - e^{-jks}}{e^{jks} - H} e^{j2k(l+s)}$$

$$|R| = \left[\frac{1 + |H|^2 - 2|H|\cos(\phi + ks)}{1 + |H|^2 - 2|H|\cos(\phi - ks)}\right]^{1/2}$$

$$\phi_R = 2k(l + s) + \mathrm{Tan}^{-1}\left[\frac{2|H|\cos\phi\sin(ks) - \sin(2ks)}{|H|^2 - 2|H|\cos\phi\cos(ks) + \cos(2ks)}\right]$$

$$R_r = \{2H_r\cos[k(2l + s)] - \cos(2kl) - (H_r^2 + H_i^2)\cos[2k(l + s)]\}/D,$$

$$R_i = \{2H_r\sin[k(2l + s)] - \sin(2kl) - (H_r^2 + H_i^2)\sin[2k(l + s)]\}/D,$$

and

$$D = 1 + H_r^2 + H_i^2 - 2[H_r\cos(ks) + H_i\sin(ks)]$$

8.4.4 *Normal Incidence Sound Absorption Coefficient*—Calculate the normal incidence sound absorption coefficient as follows:

$$\alpha = 1 - |R|^2 = 1 - R_r^2 - R_i^2$$

8.4.5 *Normal Specific Acoustic Impedance Ratio*—Calcu-

late the normal specific acoustic impedance ratio as follows:

$$z/\rho c = r/\rho c + j\, x/\rho c = (1 + R)/(1 - R)$$

8.4.5.1 *Normal Specific Acoustic Resistance Ratio*—Calculate the normal specific acoustic resistance ratio as follows:

$$r/\rho c = \alpha/[2(1 - R_r) - \alpha]$$

8.4.5.2 *Normal Specific Acoustic Reactance Ratio*—Calculate the normal specific acoustic reactance ratio as follows:

$$x/\rho c = 2R_i/[2(1 - R_r) - \alpha]$$

8.4.6 *Normal Specific Acoustic Admittance Ratio*—Calculate the normal specific acoustic admittance ratio as follows:

$$y\rho c = g\rho c - jb\rho c = \rho c/z$$

8.4.6.1 *Normal Specific Acoustic Conductance Ratio*—Calculate the normal specific acoustic conductance ratio as follows:

$$g\rho c = \frac{r/\rho c}{(r/\rho c)^2 + (x/\rho c)^2}$$

8.4.6.2 *Normal Specific Acoustic Susceptance Ratio*—Calculate the normal specific acoustic susceptance ratio as follows:

$$b\rho c = \frac{x/\rho c}{(r/\rho c)^2 + (x/\rho c)^2}$$

8.4.7 *Estimation Errors*—Because the transfer function estimates are made from sample records of finite duration and finite frequency resolution, they are susceptible to random and bias errors.

8.4.7.1 *Random Error*—Random error is generally kept low by ensemble averaging (that is, measuring several individual estimates and computing the average) or frequency smoothing (that is, averaging together the results for several frequency bands). Typically, a product of frequency bandwidth and record sample length of 50 to 100 will keep random error sufficiently low.

8.4.7.2 *Bias Error*—Bias error will be low, provided that the time length of each sample record is much larger than the acoustic propagation times within the impedance tube system, that is:

$$T \gg \frac{2l_1}{c}$$

where:

$T$ = the sample record length,
$l_1$ = the distance from microphone 1 to the end of the tube where the test specimen is located, and
$c$ = the speed of sound.

The normal time record length should be greater than 20 ms which is a frequency resolution of 50 Hz.

## 9. Report

9.1 The report shall include the following information:

9.1.1 A statement, if true in all respects, that the test was performed in accordance with this standard.

9.1.2 A description of the sample adequate to identify another sample of the same material. This includes the definition of the specimen surface, if it is irregular.

9.1.3 A description of the test specimens: their number, size, and method of mounting.

9.1.4 A tabular listing by frequency band of the absorption coefficients (to two significant figures).

9.1.5 A tabular listing by frequency band of the resistance and reactance ratios (to two significant figures).

9.1.6 The original data if several measurements have been made and the results averaged.

9.2 A description of the instruments used and the details of procedure shall also be considered part of the report. Signal processing parameters such as the frequency resolution, the number of averages, and the windowing function must also be included.

## 10. Precision and Bias

10.1 Measurements described in this standard can be made with great precision, a greater precision than is sometimes needed. The imprecision comes from sources other than the measurement procedure. Some materials are not very uniform so that specimens cut from the same sample differ in their properties. There is a real uncertainty sometimes in deciding on the location of the face of a very porous specimen. The largest causes of imprecision are related to the preparation and installation of the test specimen. The specimen must be precisely cut. The fit must not be too tight or too loose. Irregular nonreproducible airspaces behind the specimen must be prevented.

10.2 Measurements of the microphone spacing and the distance from the material surface to the center of the nearest microphone must be made to within 0.1 mm for those materials that have a well defined surface.

10.3 Since there is presently no material available with accepted reference or known true values of performance which can be used for determining the bias of this test method, no quantitative statement on bias can be made at this time.

10.4 The within- and between-laboratory precision of this test method, expressed in terms of the within-laboratory, 95 % Repeatability Interval, $I(r)$, and the between-laboratory, 95 % Reproducibility Interval, $I(R)$, has been found to be as listed in Table 1. These statistics have been based on the results of a round-robin test program involving ten laboratories testing one type of material.[9]

10.5 The significance of the Repeatability and Reproducibility Intervals is as follows:

10.5.1 *Repeatability Interval, I(r)*—On the basis of test error alone, the absolute value of the difference in two test results obtained in the same laboratory on the same material will be expected to exceed $I(r)$ only about 5 % of the time.

10.5.2 *Reproducibility Interval, I(R)*—On the basis of test error alone, the absolute value of the difference in two test results obtained in different laboratories on the same material will be expected to exceed $I(R)$ only about 5 % of the time.

[9] Supporting data are available from ASTM Headquarters. Request RR: E-33-1006.

TABLE 1 Within-Laboratory Repeatability, $I(r)$, and Between-Laboratory Reproducibility, $I(R)$

| Variable | Statistic | 125 | 250 | 500 | 1000 | 2000 | 4000 |
|---|---|---|---|---|---|---|---|
| $x/\rho c$ | $I(r)$ | 3.4 | 0.4 | 0.3 | 0.1 | 0.1 | 0.6 |
| | $I(R)$ | 14.7 | 3.3 | 1.5 | 0.4 | 0.2 | 0.8 |
| $r/\rho c$ | $I(r)$ | 2.4 | 0.5 | 0.2 | 0.3 | 0.2 | 0.2 |
| | $I(R)$ | 8.1 | 1.7 | 0.6 | 0.3 | 0.3 | 0.5 |
| $\alpha$ | $I(r)$ | 0.04 | 0.02 | 0.04 | 0.05 | 0.01 | 0.04 |
| | $I(R)$ | 0.09 | 0.08 | 0.11 | 0.12 | 0.03 | 0.07 |

## ANNEX

### (Mandatory Information)

## A1. LABORATORY ACCREDITATION

**A1.1 Scope**

A1.1.1 This annex describes procedures to be followed in accrediting a testing laboratory to perform tests in accordance with this test method.

**A1.2 Summary of Procedures**

A1.2.1 The laboratory shall allow the accrediting agency to make an on-site inspection.

A1.2.2 The laboratory shall show that it satisfies the criteria of Practice E 548.

A1.2.3 The laboratory shall show that it is in compliance with the mandatory parts of this test method: that is, those parts that contain the words "shall" or "must".

A1.2.4 The laboratory shall show the construction and geometry of the tube as described in 6.2.

A1.2.5 The laboratory shall show calculations verifying tube diameter in accordance with 6.2.2.

A1.2.6 The laboratory shall show the sound source and that its frequency response is in accordance with 6.4.1.

A1.2.7 The laboratory shall show that the signal-to-noise ratio of the source is adequate in accordance with 6.4.2.

A1.2.8 The laboratory shall report the phase response correction procedure used (see 6.5.1 and 8.3).

A1.2.9 The laboratory shall report the type of test signal used.

A1.2.10 The laboratory shall show sample calculations or the computer program used to evaluate the equations in 8.3 and 8.4.

**A1.3 Reference Tests**

A1.3.1 The laboratory shall maintain a reference specimen to be used during the periodic tests for quality assurance. It shall be so constructed or formed that it will not deteriorate quickly with use. Presumably, its absorptive properties should remain stable during at least ten years of use. The sound absorption coefficients of the reference specimen shall be at least 0.20 as measured by Test Method C 384 (at frequencies of 250 Hz and above).

A1.3.2 The laboratory shall measure the sound absorption coefficients of the massive sound-reflecting septum (see 6.3.1) at the frequency range of interest at least four times a year if testing is carried out uniformly throughout the year. Results should be compared with calculated results or with results reported in the literature.[8]

A1.3.3 The sound absorption coefficients and their standard deviations shall be analyzed by the control chart method described on Part 3 of *STP 15D*.[10] The analysis shall be in accordance with the sub-section entitled "Control-No Standard Given".

[10] *Manual on Presentation of Data and Control Chart Analysis, STP 15D*, ASTM, 1976, Part 3.